Signals and Circuits

ENGR 35500

Transistor

Chapter 17: 17-1 (DC operation of bipolar junction transistor)(pp. 781-785)

Floyd, T. L., and Buchla, D. M., *Electroics Fundamentals: Circuits, Devices & Applications*, 8th Edition, Pearson, 2009.

Chapter 3: 3-7 (Application Note: Bipolar Junction Transistor)(pp. 127-130)

Ulaby, Fawwaz T., and Maharbiz, Michael M., *Circuits*, 2nd Edition, National Technology and Science Press, 2013.

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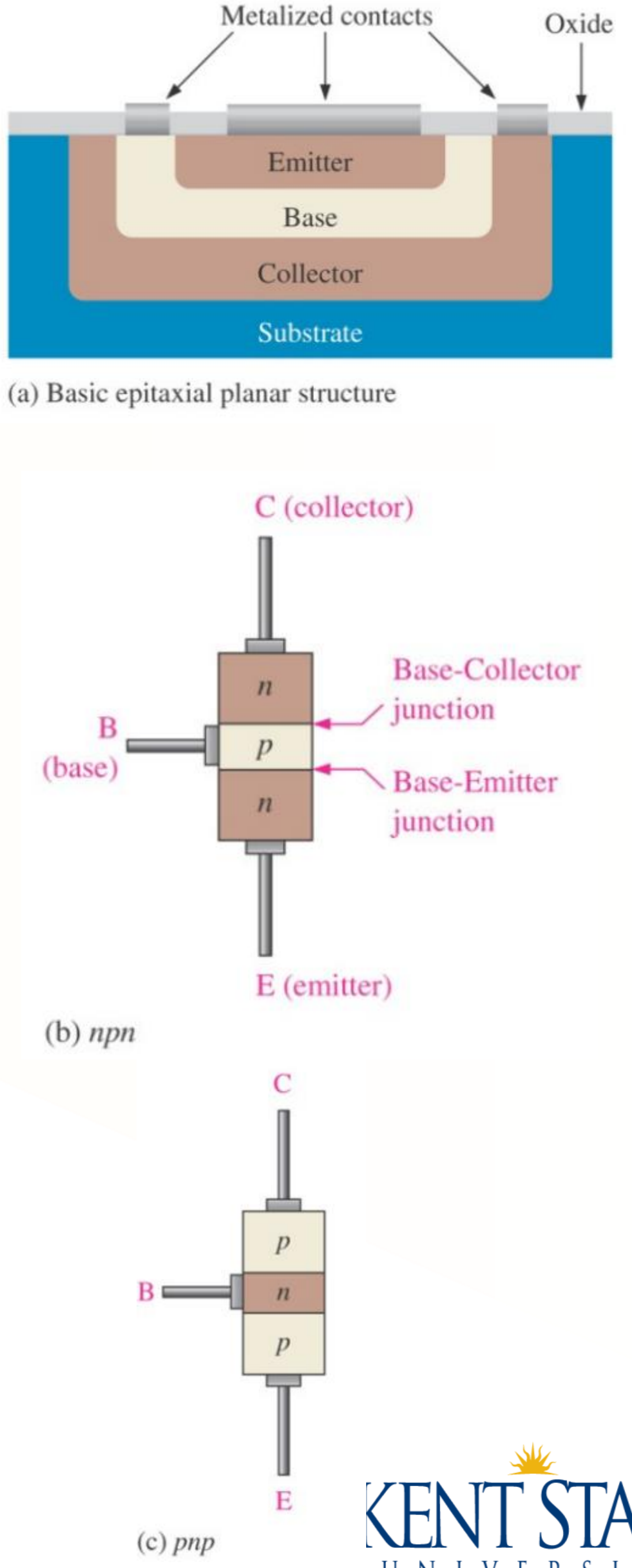
Transistor

➢Transistor construction

- A bipolar transistor is produced when a third layer is added to a semiconductor diode.
- Bipolar Junction Transistors (BJTs)
- It can amplify power, current, or voltage.
- Also called a junction transistor

➢A transistor:

- Can be constructed of germanium or silicon.
- Silicon is more popular.
- Consists of three alternately doped regions.
- The regions are arranged two ways.
  - P-type material is sandwiched between two N-type materials, NPN transistor.
  - N-type material is sandwiched between two P-type materials, PNP transistor.
  - Regions are called **emitter, base and collector**.



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Transistor

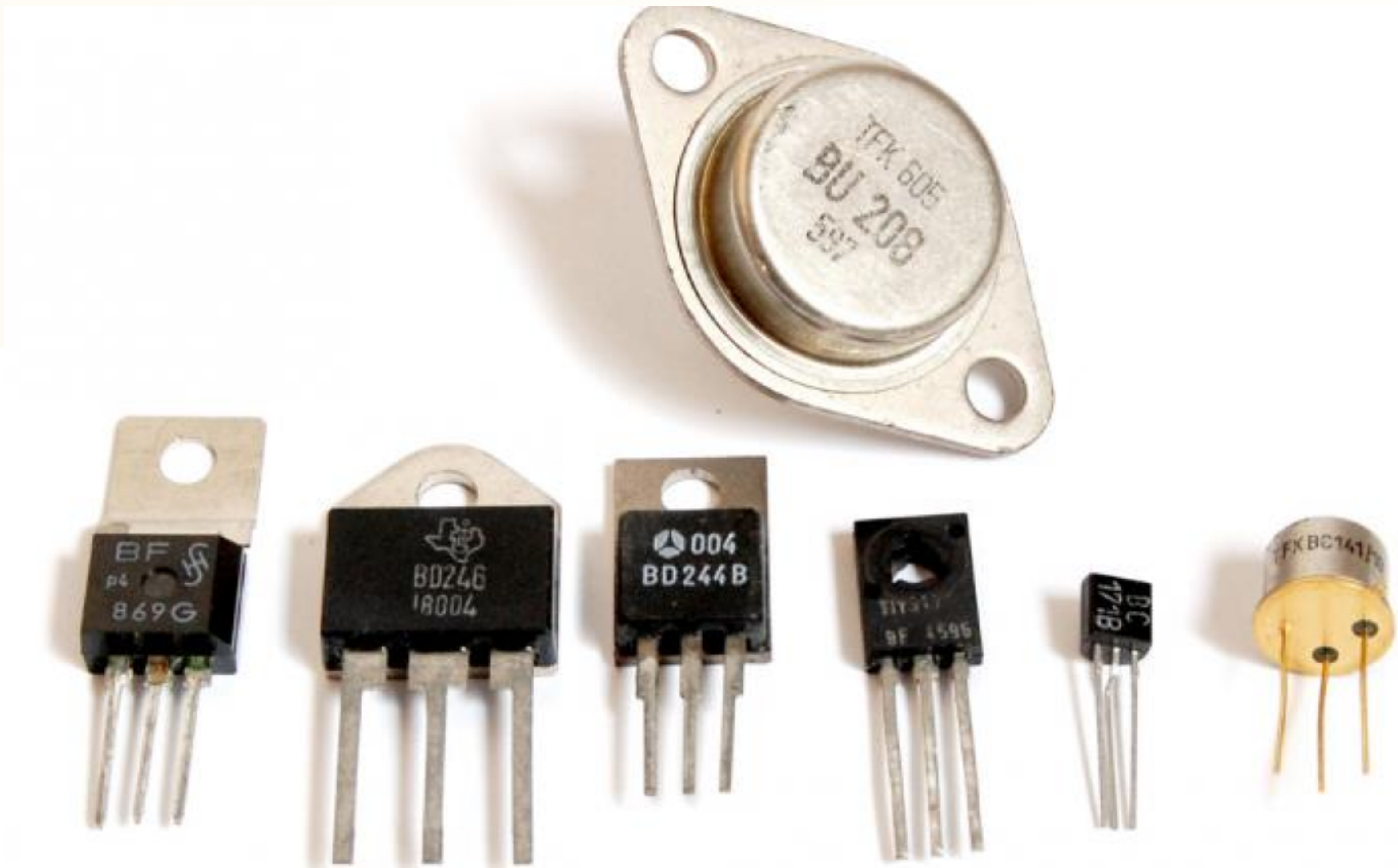

Figure: https://www.norwegiancreations.com/2016/05/an-intro-to-transistors-and-relays/

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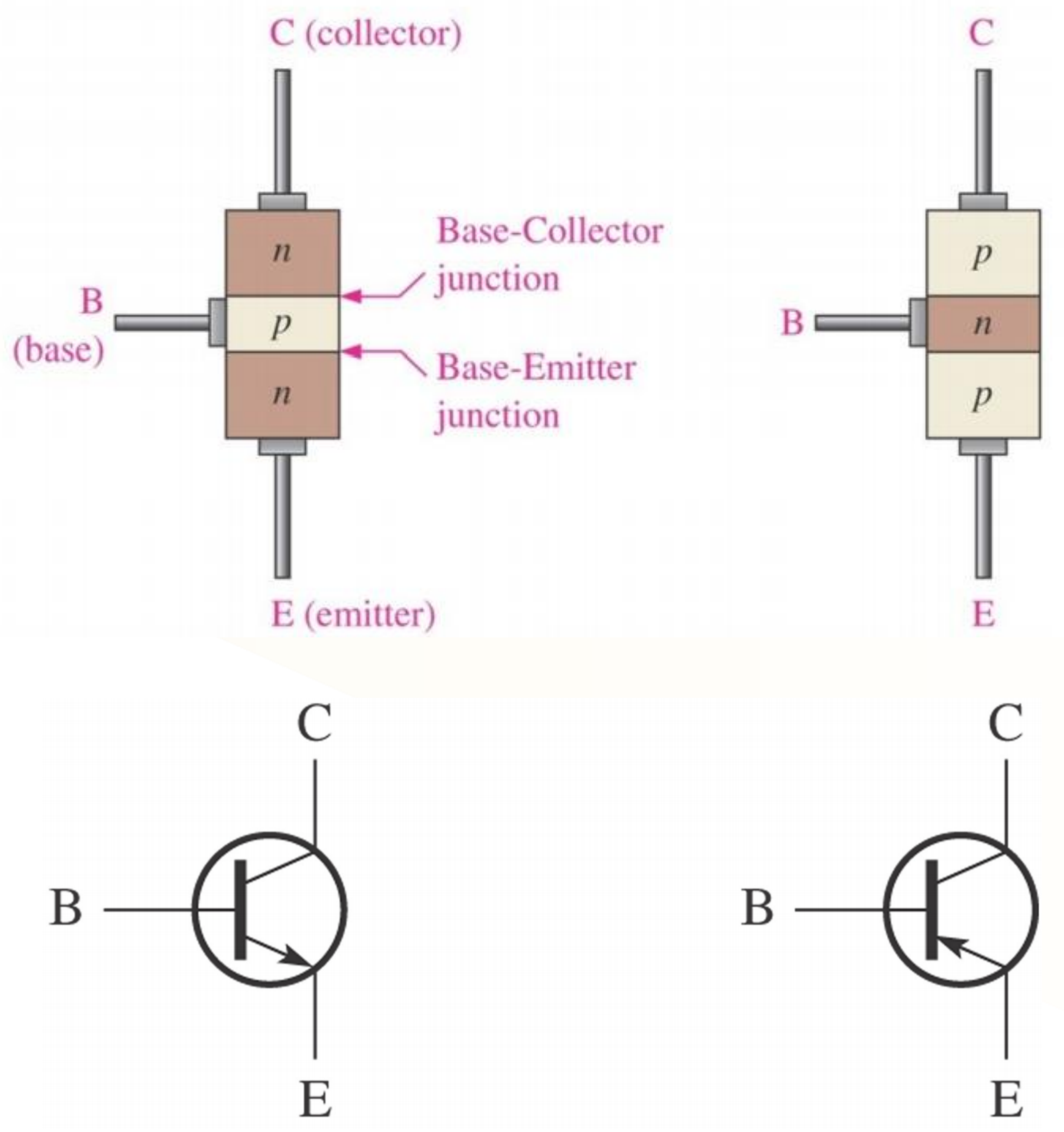
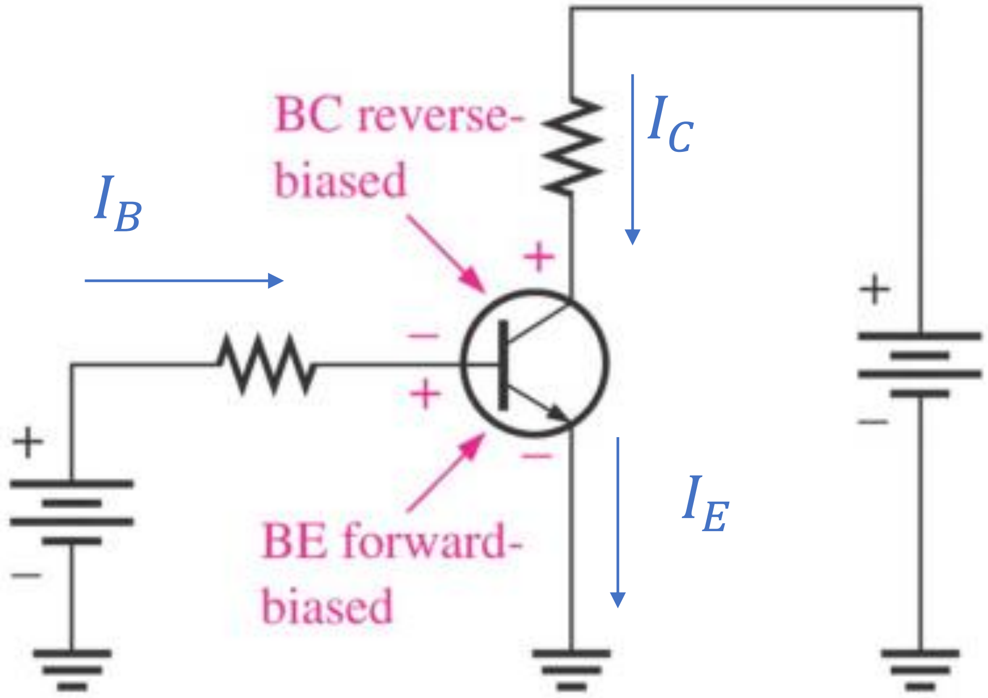
Transistor

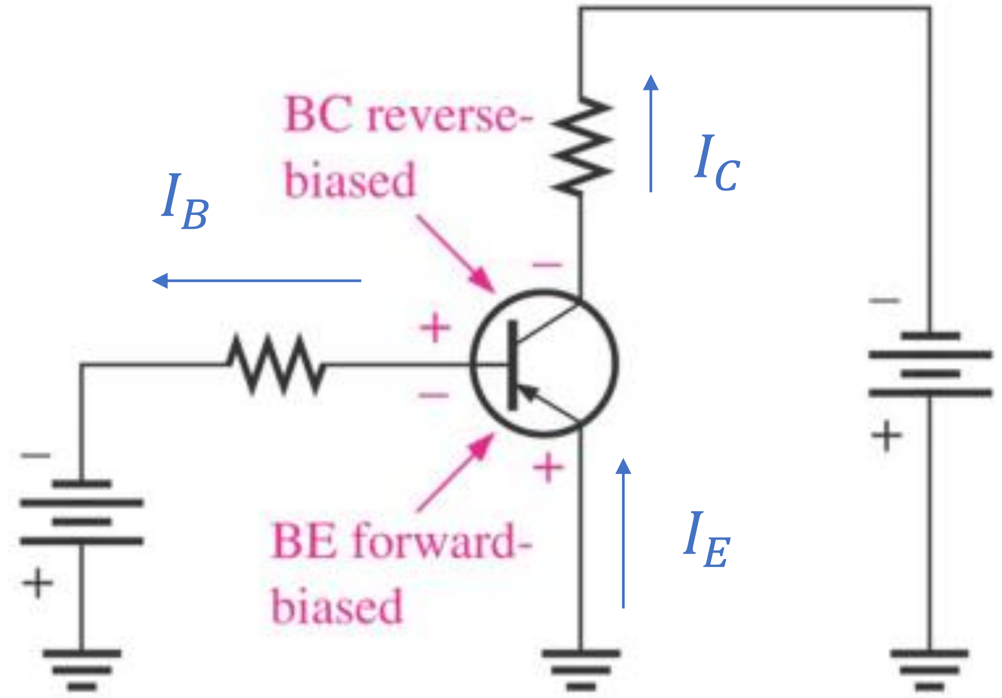


NPN **PNP**

Transistor



NPN



PNP

- A transistor must be properly biased
  - The emitter junction is forward biased.
  - The collector junction is reverse biased.
- In a transistor, the barrier voltage is:
  - produced across the emitter junction
  - determined by the type of semiconductor material used
  - the barrier voltage for a germanium transistor is .3 V
  - the barrier voltage for a silicon transistor is .7 V
  - Need to encounter the barrier voltage in the emitter-base junction to make the transistor work
- The reverse-biased voltage applied to the collector-base junction is usually much higher than the forward-biased voltage across the emitter-base junction.

- If it can not encounter the barrier voltage in the emitter-base, there is no current flowing in/out the transistor.
- If the transistor works in active region,

$$I_E = I_C + I_B$$

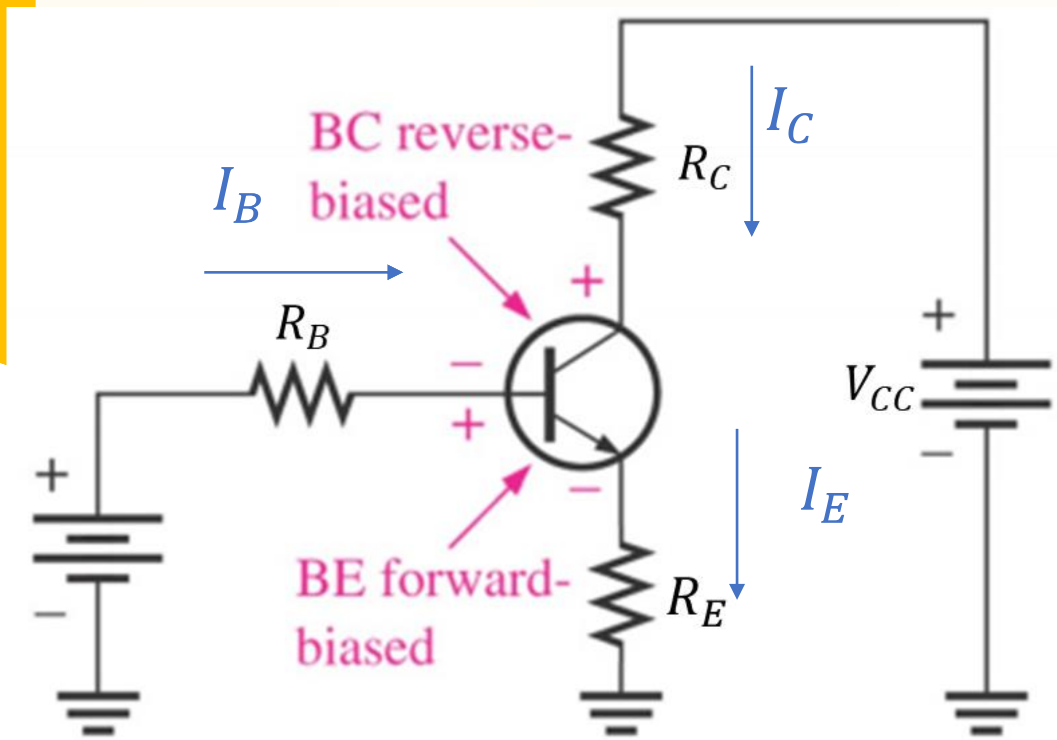
$$I_C = \beta I_B$$

β~ 20 - 200 is determined by construction of the transistor

I_B is usually very small.

$I_E \approx I_C$

Transistor



NPN

If the transistor works in active region ($I_C = \beta I_B$),

Emitter voltage and Current

$$V_E = V_B - 0.7V$$

$$I_E = V_E / R_E$$

$$I_C = \beta I_B$$

$$I_E \approx I_C$$

$$I_B = I_C / \beta$$

Collector voltage: $V_C = V_{CC} - I_C R_C$

$$V_{CE} = V_C - V_E$$

- A transistor must be properly biased
  - The emitter junction is forward biased.
  - The collector junction is reverse biased.

V_B *denotes the voltage between the base terminal to the ground.*
V_C *denotes the voltage between the collector terminal to the ground.*
V_E *denotes the voltage between the emitter terminal to the ground.*

- A transistor is trying to maintain $I_C = \beta I_B$

- The maintaining method is to adjusting V_C or V_{CE}

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DC Operation of BJTs (active region)

$E.g.$

Exercise 3-15 Determine I_B, V_{out_1}, and V_{out_2} in the transistor circuit of Fig. E3-15, given that $V_{BE} = 0.7$ V and $\beta = 200$.

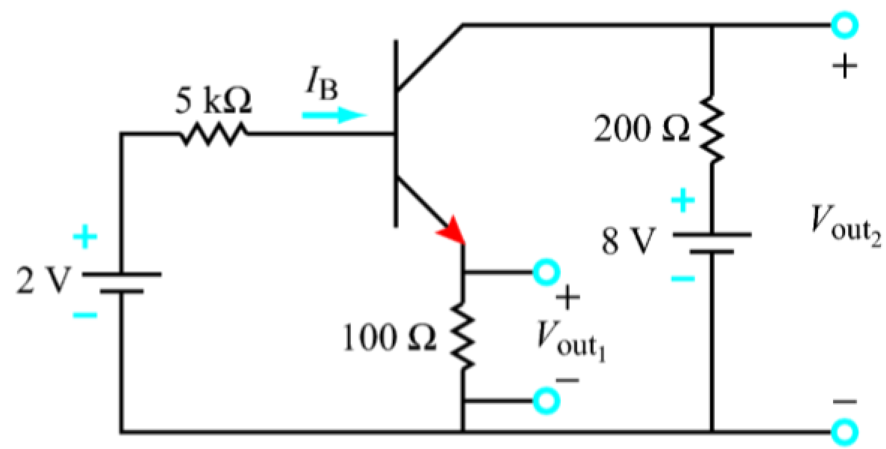


Figure E3.15

NOTE: Emitter voltage and Current

$$V_E = V_B - 0.7V$$

$$I_E = V_E / R_E$$

$$I_C = \beta I_B$$

$$I_E \approx I_C$$

$$I_B = I_C/\beta$$

Collector voltage: $V_C = V_{CC} - I_C R_C$

$$V_{CE} = V_C - V_E$$

KVL

$$-2 + 5000 I_B + V_{BE} + V_{out1} = 0$$

$V_{out1} = 100 I_E$ (Ohm's law)

$$V_{BE} = 0.7V$$

$$I_E = I_C + I_B = (\beta + 1)\, I_B = 201\, I_B$$

$$-2 + 5000 I_B + 0.7 + 20100\, I_B = 0$$

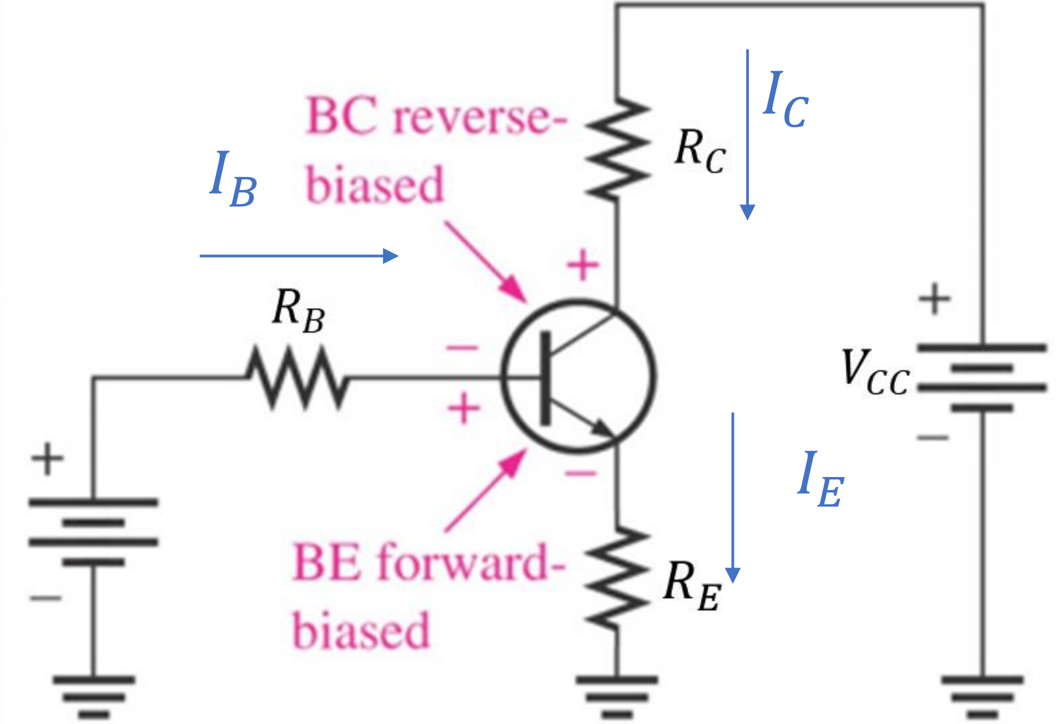
$$I_B = 51.79 \mu A$$

$$V_{out1} = 100 I_E = 20100 I_B = 1.04\text{V}$$

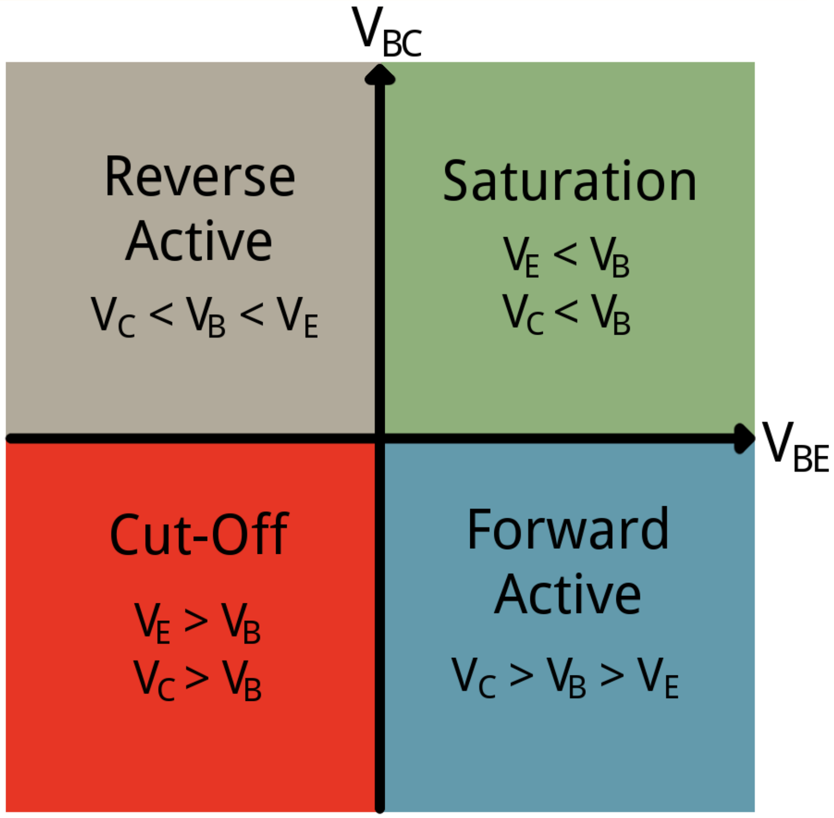
$$V_{out2} = V_C = 8 - 200 I_C = 8 - 200 \times 200 I_B = 5.93V$$

Transistor operation modes

•**Cut-off** -- The transistor acts like an **open circuit**. No current flows from collector to emitter.
•**Active** -- The current from collector to emitter is **proportional** to the current flowing into the base. ($I_C = \beta I_B,\ V_{CE} \geq 0$)
•**Saturation** -- The transistor acts like a **short circuit**. Current freely flows from collector to emitter. ($I_C \leq \beta I_B,\ V_{CE} = 0$)
•**Reverse-Active** -- Like active mode, the current is proportional to the base current, but it flows in reverse. Current flows from emitter to collector (not, exactly, the purpose transistors were designed for)



Collector voltage: $V_C = V_{CC} - I_C R_C$

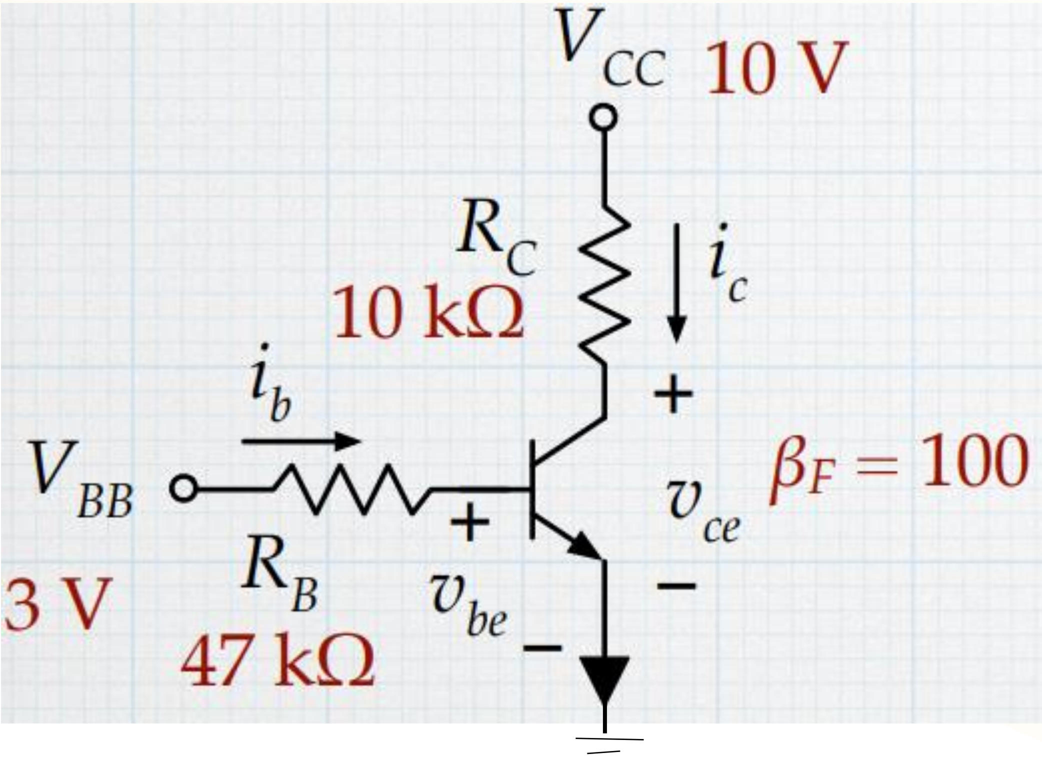


Note that: the saturation is generated since V_{CE} can not be negative.

http://engineering.sdsu.edu/~johnston/ME204/Lecture_Notes/Transistors.pdf

Transistor in saturation

For example



$$i_B = \frac{V_{BB} - v_{BE}}{R_B} = \frac{3\text{ V} - 0.7\text{ V}}{47\text{ k}\Omega} = 48.9\,\mu\text{A}$$

If active region

$$i_C = \beta_F i_B = (100)\left(48.9\,\mu\text{A}\right) = 4.89\text{ mA}$$

$$\begin{aligned} v_{CE} &= V_{CC} - i_C R_C \\ &= 10\text{ V} - (4.89\text{ mA})\left(10\text{ k}\Omega\right) = -38.9\text{ V} \end{aligned}$$

???

Emitter voltage and Current

$$V_E = V_B - 0.7V$$

$$I_E = V_E / R_E$$

$$I_C = \beta I_B$$

$$I_E \approx I_C$$

$$I_B = I_C/\beta$$

Collector voltage: $V_C = V_{CC} - I_C R_C$

$$V_{CE} = V_C - V_E$$

$V_{CE} \geq 0$ (always)

Corrected solution:

$$i_B = \frac{V_{BB} - v_{BE}}{47k\boldsymbol{\Omega}} = \frac{3v - 0.7}{47k\boldsymbol{\Omega}} = 48.9\ uA$$

$$V_{CE} = 0$$

$$i_C = \frac{V_{CC} - v_{CE} - V_{EGroung}}{R_C} = \frac{10v}{10k\boldsymbol{\Omega}} = 1000\ uA$$

$$i_E = i_B + i_C = 1048.9uA$$